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National Aerospace Laboratory NLR

AMS Tracker Thermal Control Subsystem

Appendix A: Accumulator Safety Input Definition

APPENDIX TO AMSTR-NLR-TN-018
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Contents

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1 Introduction

In this appendix the design information needed to pass the safety review is specified. The document starts with a list all the hazard reports requiring information on the TTCS accumulator. In section some critical design information for specific points is specified which is needed for the hazard reports as identified in section 2. Section 4 focusses on the qualification of welds and summarises the information which can be found in the procedures listed.

2 Hazard Reports information

Hazard reports are reports which are delivered to the NASA safety board. Based on this information the NASA safety board will decide whether a design, manufacturing process, handling procedure is acceptable. Within the AMS02 project a AMS02 safety officer (Leland Hill) will collect the information prior to the review of the safety board. The safety officer selected the hazard reports which need information from the accumulator design.

AMS-02-F05: Rupture of pressurize systems

1.1	The AMS-02 hardware is being designed to provide positive margins using appropriate factors of safety. The attached table provides the MDP, factors of safety and associated margins for the pressurized systems addressed in this hazard report. The loading factors and conditions, mechanical, pressure and thermal have been considered in establishing a positive margin of safety of the pressure systems associated with the pressurized systems.	**1.1.1**	AMS-02 Pressure Systems Structural/Stress Analysis and Tests as defined in AMS-02 SVP (JSC 28792).
2.1	All AMS-02 pressure system materials will be selected to meet the requirements of MSFC-STD-3029 for stress corrosion cracking. Materials with high resistance to stress corrosion cracking will be used where possible. Where materials with moderate to low resistance to stress corrosion cracking are utilized, MUAs have been prepared and will be submitted for approval.	**2.1.1**	Stress Corrosion Evaluation of materials list and drawings.
2.1	All AMS-02 pressure system materials will be selected to meet the requirements of MSFC-STD-3029 for stress corrosion cracking. Materials with high resistance to stress corrosion cracking will be used where possible. Where materials with moderate to low resistance to stress corrosion cracking are utilized, MUAs have been prepared and will be submitted for approval.	**2.1.2**	ES4/Material and Processes Branch Certification Letter for materials usage.

2.2	Working fluids/gasses are inert and will be non-reactive, with the exception of ammonia. All working fluids are compatible with all materials of construction. *Materials of construction are principally stainless steel.*	**2.2.1**	Materials Compatibility Assessment
2.2	Working fluids/gasses are inert and will be non-reactive, with the exception of ammonia. All working fluids are compatible with all materials of construction. *Materials of construction are principally stainless steel.*	**2.2.2**	Approval of material use and MUAs by JSC ES4/Materials and Processes Branch
2.3	Cleaning materials will be compatible with working fluid and materials of construction.	**2.3.1**	Materials Compatibility Assessment/Review
2.4	Metallic materials that touch in the pressure system will be assessed for potential galvanic reactions that could degrade welds and other joints.	**2.4.1**	Material Compatibility Assessment
2.4	Metallic materials that touch in the pressure system will be assessed for potential galvanic reactions that could degrade welds and other joints.	**2.4.2**	Approval of material use and MUAs by JSC ES4/Materials and Processes Branch MUA: Materials Usage Agreement
6.1	All pressurized systems will be filled with high purity gases and appropriate quantities.	**6.1.4**	Manufacturers' certifications on filling of Ammonia Heat Pipes.

AMS-02-F05 Manufacturing information.

3.1	Manufacturing and Assembly AMS-02 pressurized systems will be done in accordance with approved drawings and procedures. Manufacturing and Assembly processes have certification processes in place to document compliance with approved drawings and procedures.	**3.1.1**	All discrepancies and deviations from approved drawings/procedures are reconciled through a MRB process to assure compliance with requirements. MRB: Material Review Board
3.2	All welds will have a positive margin of safety during all mission phases for the factors of safety specified in the AMS-02 Structural Verification Plan (SVP) JSC 28792C. (which includes pressurized systems.)	**3.2.1**	Review of weld plans, processes and certification of welds of the AMS-02 systems.
3.2	All welds will have a positive margin of safety during all mission phases for the factors of safety specified in the AMS-02 Structural Verification Plan (SVP) JSC 28792C. (which includes pressurized systems.)	**3.2.2**	Proof Pressure Testing, Dye Penetrant inspection, Radiological (or ultrasound) inspection of welds.

Remark: More detailed information on the weld procedures can be found in section 5.

AMS-02-F05 Fracture Control Data

4.1	The AMS-02 pressurized systems uses JSC 25863A to implement the fracture control requirements of NASA-STD-5003 and SSP 30558C.	**4.1.1**	Compliance with the fracture control requirements of NASA-STD-5003 and SSP-30558C will be verified by approval of fracture control summary by JSC ES4/Materials and Processes Branch.

8.5	TTCS ACCUMULATOR HEAT PIPE/TTCS ACCUMULATOR. The TTCS Accumulator is heated by the TTCS accumulator heat pipe that is situated down the center of the accumulator. The accumulator heat pipe extends out of the accumulator and is fitted with heaters that will drive the overall pressure of the TTCS system. These heaters will be controlled by thermostatic control devices that are attached to the heat pipe by way of a thermally conductive fixture. The thermostatic control for the heaters is two fault tolerant, with one thermostatic control device	**8.5.1**	Review of Design for inclusion of heater thermostatic control and thermal threshold values

	implemented in the return leg of the heaters. In addition to heater control by thermostatic devices, the pressure of the TTCS is monitored and a computer system is capable of shutting down the heaters if the pressure is too high for efficient operations.		
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8.5	TTCS ACCUMULATOR HEAT PIPE/TTCS ACCUMULATOR. The TTCS Accumulator is heated by the TTCS accumulator heat pipe that is situated down the center of the accumulator. The accumulator heat pipe extends out of the accumulator and is fitted with heaters that will drive the overall pressure of the TTCS system. These heaters will be controlled by thermostatic control devices that are attached to the heat pipe by way of a thermally conductive fixture. The thermostatic control for the heaters is two fault	**8.5.3**	Functional testing/Acceptance Testing of thermostatic switches.

	tolerant, with one thermostatic control device implemented in the return leg of the heaters. In addition to heater control by thermostatic devices, the pressure of the TTCS is monitored and a computer system is capable of shutting down the heaters if the pressure is too high for efficient operations.		
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AMS-02-F10: Flammable Materials in the Payload Bay

2.6	The TTCS Accumulator Heat Pipes utilize 3 grams of ammonia as a working fluid. The TTCS Accumulator Heat Pipe is a closed system that does not incorporate any nominal venting means. The TTCS Accumulator Heat Pipe is qualified under NSTS 1700.7B, 208.4C Pressurized Lines Fittings and Components. Reference AMS-02-F05.	**2.6.1**	Review of design to establish flammable material quantity
2.6	The TTCS Accumulator Heat Pipes utilize 3 grams of ammonia as a working fluid. The TTCS Accumulator Heat Pipe is a closed system that does not incorporate any nominal venting means. The TTCS Accumulator Heat Pipe is qualified under NSTS 1700.7B, 208.4C Pressurized Lines Fittings and Components. Reference AMS-02-F05.	**2.6.2**	Flammability assessment on the use of ammonia in the payload bay.

AMS-02-F04: Over-pressurisation of payload bay doors

5.7	TTCE Accumulator Heat Pipe contains 3 grams of ammonia. The TTCS Accumulator Heat Pipe is a closed system qualified under DFMR and has no nominal or fault venting conditions, reference AMS-02-F05.	**5.7.1**	Review of Design

3 Specific design information needed to pass the safety review

In this section some specific design information requested in section 2 is more detailed and explained. However section 2 should be used as official reference.

3.1 Heat Pipe ammonia information

In order to check no over-pressurisation of the heat pipe occurs. Information is needed on:

1. Total mass of ammonia used
2. Total container volume of the heat pipe
3. Details on the ammonia filling procedure to verify the right amount of ammonia is filled in the heat pipe
   a. Manufacturer's certification of a proper fill

3.2 List of materials

A list of materials with certificates and a list of fluids used during manufacturing is needed for approval. This list is used for many of the in section 2 listed hazard reports. QM/FM manufacturing can only start when the material specifications are listed and send to the safety board.

Remark: The use of American international standard materials is strongly advised. For Chinese alloys more paperwork and additional information is needed to find out the US alloy equivalent.

3.3 Liquid entrance pipe bracket design (inside the accumulator)

The design should show the liquid entrance pipe fulfils the structural/stress analysis and tests. One of the identified issues is that it should be shown the liquid entrance pipe is not rigidly fixed at both sides. By such a construction the liquid entrance pipe could break or induce stress on the pressure vessel. Therefore the construction of the liquid entrance pipe bracket should be presented to a level of detail which is sufficient for the review board to verify one side is sliding.

3.4 Heat pipe sleeve at the far end of the accumulator

The design should show the liquid heat pipe fulfils the structural/stress analysis and tests. One of the identified issues is that it should be shown that the accumulator heat pipe is not rigidly fixed at both sides. By such a construction the accumulator heat pipe could break or induce stress on the pressure vessel.

Therefore two things are requested:

- Information on the construction of the heat pipe sleeve at the far end of the accumulator to a level of detail which is sufficient for the review board to verify that the heat pipe can slide in the sleeve and sliding space is sufficient
- A short procedure of how it is verified that the heat pipe installed at the exact location in the sleeve

3.5 List of safety critical fasteners

A list of safety-critical fasteners (screws, bolts etc) used in the construction should be delivered. The list should also give information on the method of back-off prevention.

3.6 Heat Pipe Maximum Design Temperature and Maximum Design Pressure

For the heat pipe the maximum design pressure and temperature should be calculated.
Remark: For the accumulator the Maximum Design Pressure and Maximum design temperature are provided by NLR.

3.7 Accumulator stress analysis showing positive margins of safety

This is needed to show rupture of the TTCS as pressurised is not possible (hazard report AMS02-F05). Below a summary of the worst case accumulator loads is given.

3.7.1 Loads during launch

	Acceleration loads
Pressure load 160 bar	+65 °C + possible CTE stress
Pressure load 10.1 bar	-40 °C + possible CTE stress

Table 1: Load combinations during launch

During launch/landing only combination of pressure loads and acceleration forces is possible. No combination of acceleration loads and heater induced thermal stress is possible, as no TTCE power is available during launch. Combined with the fact that the TTCS boxes are well insulated the TTCS accumulator will have a uniform temperature during launch and descent. This uniform temperature distribution will only produce stress at the interfaces between different materials (different CTE); These stresses have to be evaluated.
First perform the red case.
Being the pressure load in the second case negligible compared to the first we will discuss with Jacobs the need to perform the green case.

3.7.2 In orbit loads

	Thermal stress load due to heating
Pressure load 160 bar	Maximum gradient due to HP wire heaters
Pressure load 160 bar	Maximum gradient due to Peltier cooler dissipation
Pressure load 51 bar	Maximum gradient between operating accu at setpoint T=+15 °C and the cold fluid (-40 °C) in the Peltier HX tubes

Table 2: Load combination in orbit

In orbit a combination of the pressure load and thermal stress due to the heating of heaters is possible. The most critical cases are defined to be:

HOT

1. When Accumulator Emergency Heaters and Accumulator control heaters are switched on full power, the heat pipe is still operating but the loop is not running. Take the temperature profile at the time where the third Thermal Switch on the heat pipe will switch. This induces the worst case temperature profile.
2. When the Peltier elements are all dissipating maximum power and the loop is not running. Take the temperature profile close to the point where the Thermal Switches switch the heaters off.
3. Take a combination of cases 1 and 2

COLD

1. Accumulator runs at +15 °C and cold fluid (-40 °C) runs through the tube.

First perform the red cases.

Being the pressure load in the green case negligible compared to the first two cases we will discuss with Jacobs the possibility not to perform the green case.

4 Specific design information for mission success

In order to verify mission success also the following information is requested.

4.1 Spot weld information

In order to verify that the accumulator design will fulfil the liquid feed rate requirement the amount of liquid behind the wick should be known. Critical parameter for the estimation of the fluid behind the wick is the interspacing of the spot welds of the wick.

4.2 Cleanliness verification

As for operation of heat pipes, loop heat pipes and other two-phase systems cleanliness is critical. Information is requested how cleanliness of the accumulator is verified (e.g. particle count method).

5 Weld information

One of the most critical items for safety is the weld specification and weld verification. NASA requires detailed information on welds, weld parameters and on weld verification.

Information is requested on:

- DESIGN REQUIREMENTS
- MATERIAL REQUIREMENTS/SPECIFICATIONS
  - SHIELDING GASES
  - FILLER METALS AND ELECTRODES
- PROCESS REQUIREMENTS
  - PROCESS-SPECIFIC REQUIREMENTS
  - WELD QUALIFICATION
  - PREHEATING (IF ANY)
  - POST WELD HEAT TREATMENT (PWHT)
- PROCESS VERIFICATION
  - INSPECTION
  - VISUAL INSPECTION REQUIREMENTS
  - NON-DESTRUCTIVE EVALUATION (NDE)
- PROCESS DOCUMENTATION REQUIREMENTS
  - WELDING PROCEDURE SPECIFICATION
  - PROCEDURE QUALIFICATION RECORD
  - WELDING OPERATOR PERFORMANCE QUALIFICATION
  - DEVIATIONS AND WAIVERS
- TRAINING AND CERTIFICATION OF PERSONNEL
  - TRAINING
  - WELDING OPERATOR QUALIFICATION

One of the most important requirements is the weld qualification and copied below. It is requested to deliver at least 9 weld samples of the same material used for the real weld.
More information can be found in NASA-PRC-010 Rev C, “Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware”.

6.3 WELD QUALIFICATION

This specification provides specific allowances for components that are fabricated for pressure containing applications and non pressure containing (i.e., structural only) applications.

6.3.1 Pressure Containing Components

A Welding Procedure Specification (WPS) shall be qualified for each unique weld type (as detailed in 6.3.1.1) to be produced, before the production welds are made. An existing qualified WPS for one unique weld type may be used for a different engineering drawing provided the requirements of 6.3.1.1 are met, and it is demonstrated that the essential weld variables listed in Table V will be met. Demonstration shall constitute all the requirements of Section 6.2.3 except that no additional documentation is required except, when a WPS(s) is written for a specific item(s) of hardware, it shall be revised/amended to show allowance for use on other than the initial specifically stated hardware. The actual welding variables, methods, practices, specific tooling requirements, and test results used during WPS qualification shall be recorded on a Procedure Qualification Record (PQR).

6.3.1.1 Unique Weld Type

A “Unique Weld Type” includes those weld joint configurations that differ from one another in any of the following respects:

1. Base material thickness,
2. Base material type (M-number/alloy),
3. Square groove joint vs. bevel, V, or U-groove joints,
4. Groove joint vs. fillet weld,
5. Addition or deletion of filler material,
6. Addition, deletion, or change in the Preheat, Interpass, or Post Weld Heat Treat (PWHT) requirements.

6.3.1.2 Test Requirements

At a minimum, the following are minimum requirements for the qualification of a welding procedure. This effort shall include the welding of a minimum of 9 weld samples that represent the weld type specified. Three of these welds shall be made at a “nominal” heat input setting, 3 shall be made at a “limit low” heat input setting, and 3 shall be made at a “limit high” heat input setting. All samples shall be visually inspected on the O.D. and I.D. to Class A criteria and radiographically inspected to Class A criteria. If the weld procedure includes a PWHT, the radiographic inspection shall, at a minimum, be performed after the PWHT cycle. Two samples from each group shall be mechanically tested in tension and the results evaluated to the requirements of AWS B2.1. One sample from each group shall be sectioned and metallographically examined and the results evaluated to the requirements of AWS B2.1. Photomicrographs shall be taken of the prepared samples and retained with the PQR.

6.3.1.3 Essential Variables

The WPS shall specify all of the essential welding variables and the applicable allowable ranges qualified for each variable, as indicated in Table V. In addition, the WPS shall detail all methods, practices, specific tooling requirements that are determined necessary by the operating facility to successfully execute the weld in production.

Table V - Essential Welding Variables

Variable #	Variable / Weld Type	Range Allowed
1	Power Source Model #	None
2	Weld Head Model #	None
3	Joint Configuration	None
4	Groove Angle	+/- 5^{o}
5	Nominal Tube Dia.	None
6	Nominal Wall Thickness	None
7	Material Type(s)	None
8	Electrode Start Position	+/- 60^{o}
9	Preweld Cleaning Steps	None
10	Allowable Joint Gap	None
11	Tool or Shop Aid Identification	None
12	Preweld Purge Time	(1)
13	Postweld Purge Time	(1)
14	Tube ID Prepurge Flow Rate or Pressure	None
15	Weld Head Prepurge Flow Rate	+/- 15%
16	Plasma Gas Flow Rate	+/- 10%
17	Gas Composition/Spec.	None
18	Electrode Travel Speed & Machine Setting	None
19	Arc Travel Start Delay	None
20	Total Weld Current On Time	None
21	Weld Time @ Level or Circumference Interval	None
22	Current Pulse Width (%)	None
23	Current Pulse Rate	None

24	Filler Material / Spec.	None
Variable #	Variable / Weld Type	Range Allowed
25	Filler Wire Feed Speed	+/- 50%
26	Consumable Insert Type and Specification	None
27	Tubular Sleeve Spec.	None
28	Background Welding Current	None
29	Pulse Welding Current	None
30	Electrode Type	None
31	Electrode Diameter	None
32	Electrode Tip Geometry	None
33	GTAW Electrode to Work Gap (nom. setting)	+/- 10%
34	PAW Electrode Position Setting (nom. setting)	+/- 10%
35	PAW Orifice Size	None
36	Minimum Preheat Temp.	None
37	Maximum Interpass Temp.	None
38	PWHT Procedure/Spec.	None